APPLICATIONS OF CONVEX POLYGON AND KERNEL DENSITY ANALYSES TO MODEL THE HOME RANGES OF EQUATORIAL SPITTING COBRA *Naja sputatrix* (BOIE, 1827) IN GREEN AREAS OF UNIVERSITAS INDONESIA CAMPUS, WEST JAVA

APLIKASI ANALISIS CONVEX POLYGON DAN DENSITAS KERNEL UNTUK PEMODELAN DAERAH JELAJAH KOBRA EKUATORIAL *Naja sputatrix* (BOIE, 1827) DI RUANG HIJAU KAMPUS UNIVERSITAS INDONESIA, JAWA BARAT

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ABSTRAK

Naja sputatrix (Boie, 1827) atau dikenal sebagai kobra ekuatorial adalah salah satu ular berbisa yang menghuni kawasan hijau yang luas termasuk Kampus Universitas Indonesia. Saat ini kobra terancam keberadaan dan pelestariannya, maka itu penting untuk mempelajari kemungkinan daerah jelajah kobra. Penelitian ini bertujuan untuk memodelkan daerah jelajah kobra di kawasan hijau Kampus Universitas Indonesia. Model dikembangkan menggunakan aplikasi *Convex Polygon* dan Densitas *Kernel*. Analisis *Convex Polygon* menunjukkan bahwa sekitar 114,53 Ha atau setara dengan 35,79% kawasan hijau Kampus Universitas Indonesia merupakan habitat jelajah kobra. Berdasarkan analisis densitas *Kernel*, diketahui bahwa hingga 307,65 Ha atau setara dengan 96,14% kawasan hijau Kampus Universitas Indonesia berpotensi sebagai habitat jelajah kobra. Berdasarkan hasil dapat disimpulkan bahwa setidaknya 30-90% kawasan hijau Kampus Universitas Indonesia perlu dilestarikan untuk mendukung keberadaan *N. sputatrix*.

Kata kunci: kobra, *Convex Polygon*, daerah jelajah, Densitas Kernel, ruang hijau.

ABSTRACT

Naja sputatrix (Boie, 1827) or known as equatorial spitting cobra is one of venomous snake inhabiting wide green areas include Universitas Indonesia Campus. Currently the existence and conservation of cobra is threatened, then it is important to study cobra possible home ranges. This research is aiming to model the home range of equatorial spitting cobra in green areas of Universitas Indonesia Campus. The model was developed using the applications of Convex Polygon and Kernel Density. The Convex Polygon analysis shows that approximately 114.53 Ha or equals to 35.79% of green areas of Universitas Indonesia Campus was the home ranges of the cobra. While, based on the Kernel Density analysis, it confirms that up to 307.65 Ha or equals to 96.14% of green areas of Universitas Indonesia Campus were potentials as the home ranges of the cobra. Then it can be concluded that at least 30-90% of green areas of Universitas Indonesia Campus should be conserved to support the presences of *N. sputatrix*.

Keywords: Cobra, Convex Polygon, green area, home range, Kernel Density.

INTRODUCTION

Equatorial spitting cobra or also known as *N. sputatrix* has wide distributions mainly covering regions of Southern parts of Indonesia that include Java Island followed by archipelago of Bali, Lombok, Sumbawa, and distributed to the Eastern parts covering Padar, Rinca, Komodo, Flores, Adonara, Lomblen, and Alor in the most Eastern parts. This species presumably is occurring in Sumatra Island (Iskandar *et al*. 2012). In Indonesia, this species occupies low-lands up to about 600 m above sea level. *N. sputatrix* commonly inhabiting wide ranges of natural terrestrial ecosystems covering rice fields, savanna, and occasionally inhabiting secondary forest. This species is also known inhabiting disturbed ecosystem ranging from open agroecosystems to open habitat associated to the presences of human settlements. Currently, all known localities of this cobra species are including lowlands up to about 600 m above sea level in general and specifically in plantations, rice fields, human made habitat, and natural habitats covering grassland, swamp, and savanna (Mumpuni 2018,Widhiantara & Rosiana 2014, Ananda 2021).

Home range represented by animal movement is a proxy of fundamental activity of an organism in many ecological systems, space and time (Riotte-Lambert & Matthiopoulos 2020). Home range is also defined as the area across which animals move during typical behaviors such as resource collection, reproduction, and regulated by environmental variables and inferring habitat use (Tikkanen *et al*. 2018). In comparison to potential habitat and occupancy areas, home range can be defined as the quantitatively delineated limits in size and space of potential habitat and occupancy areas. Recently, home range has been quantified as densities of use calculated from estimates of the animals' locations across a landscape (Powell & Mitchell 2012). The quantification methods include kernel density and convex-hull estimators, assisted with radio telemetry, GPS collar technology, non-invasive methods, and capture-recapture of animals to collect the data. Home range calculation differed from the estimations of potential habitat and occupancy areas and was presented as a probability distribution showing the probabilities of where an animal might have been found at any randomly chosen time.

Currently there are 2 methods principally used to assess the home range and also included reptile home ranges. Those methods are Convex Polygon (CP) and Kernel Density (KD) (Reshamwala *et al*. 2022). Traditional home range estimators, using CP and KD are still widely used in recent work. CP provides an outline of an individual's outer-most movements, including large areas never used by the animal and ignoring any selection patterns. In contrast, KD includes parameter choices that severely affect overall area estimates and assume independence. With the emergence of Global Positioning System (GPS) animal monitoring, the CP and KD methods are considering as the most versatile approaches to assess reptile home ranges include snakes.

CP and KD methods have been used widely to assess the home ranges of snakes. In Central Florida, Breininger *et al*. (2011) confirms that by using CP the potential home ranges of Eastern Indigo Snakes were 76 Ha for female and 202 Ha for male. While the KD methods confirm the potential home ranges of Eastern Indigo Snakes were 44 Ha for female and 156 Ha for male. In ecosystems dominated by pine and oak covers sizing 1418 Ha, Zappalorti *et al*. (2015) using KD methods confirms Northern Pinesnakes (*Pituophis m. melanoleucus*) has home ranges ranging from 38.99 Ha to 133.15 Ha.

Universitas Indonesia Campus (UIC) was known as one of campus that has vast green areas providing suitable habitats for wildlife ranging from insects (Akbar & Basukriadi 2021, Basukriadi *et al.* 2021), mammals (squirrels, bats), birds, amphibians, to snakes. Those presences of wildlife as potential preys combined with suitable habitats then can provide ecosystems suitable for terrestrial predators including venomous snakes. Regarding the sizes of green areas in UIC then information on the sizes of home range required by predators is urgently needed. Then this study aims to model the home range of equatorial spitting cobra in green areas of Universitas Indonesia Campus.

Figure 1. Study area located at the green areas of Universitas Indonesia Campus, Depok,West Java.

MATERIALS AND METHODS

Study Area

The study areas (Figure 1) were the green areas of Universitas Indonesia Campus within the geographically boundaries of 702275.17 easting and 9296133.44 northing of Universal Transverse Mercator (UTM) zone of 48M at elevation of 74.42 meters. This campus has a total area of 320 Ha. The green areas are described as the presences of vegetation patches in various sizes combined with the built areas in the form of settlements.

N. sputatrix Surveys

The survey methodology was following Barnes *et al*. (2017) and Origia *et al*. (2019). The survey was conducted in green areas of Universitas Indonesia Campus using visual surveys. The times for a 1 month survey were following activity time of *N. sputatrix* that was during the dry season in August 2022 and divided into the morning between 06:30-11:00 and afternoon 16:00-20:00 surveys. The surveys were implemented for 5 days/week. The captured *N. sputatrix* was identified and marked (Greenberg & McClintock 2008). Simultaneously, the locations where *N. sputatrix* was captured was marked using handheld GPS (Garmin Etrex) (Bista *et al*. 2021). The identification of *N. sputatrix* was using Cox *et al*. (1998) as the field guide. The markings of snakes using non-invasive medical cautery unit on ventral scale (Ekner-Grzyb *et al*. 2011) and followed by capture-recapture methods (Rose *et al*. 2018). The captured individuals were measured for their snout to vent length (SVL) in cm (Cundall *et al*. 2016).

Convex Polygon Method

Following Silva *et al*. (2020), this study calculated the Convex Polygon (CP), which is the lowest area convex polygon encompassing all *N. sputatrix* positions. The 95% CP was utilized to eliminate outlying points based on the idea that they are exploratory movements and hence not part of the home range. The CP method has long been praised for its ability to maintain comparability and historical consistency.

Kernel Density Methods

Kernel Density (KD) method was developed based on a smoothing parameter (bandwidth, h) to generate a utilization distribution and home range. KD home range model was developed using KD with reference h bandwith value or KD_{href} providing a contiguous 95% Kernel home range (Chynoweth *et al*. 2015). Another KD home range model was developed using least-squares cross-validation or KD_{hLSCV}.

Spatial Visualization

The home range data retrieved from CP and KD methods then tabulated into attribute table. By using Geographical Information System (GIS) with ArcView 3.2, those data then mapped and visualized.

Ecological Covariate

Ecological covariate measured in this study was NDVI (Normalized Difference Vegetation Index) using method following Philiani *et al*. (2016), Kawamuna *et al*. (2017), and Sukojo and Arindi (2019). NDVI is described as a simple graphical indicator that can analyze remote sensing measurements, often from a space satellite platform, assessing whether the target being observed contains live green vegetation. The NDVI was measured by analyzing the wavelength of satellite images retrieved from Landsat 8 containing vegetation images and, in this study were vegetation covers at the green areas of Universitas Indonesia Campus, Depok,West Java.

This measurement is possible since the cell structure of the vegetation leaves strongly reflects near-infrared light wavelengths ranging from 0.7 to 1.1 µm. The calculation of NDVI for each pixel of vegetation pixel was as follows:

NDVI = near invisible red wavelength – red wavelength / near invisible red wavelength + red wavelength

The NDVI was denoted as 0 (no vegetation) to 1 (high vegetation density). Using SAGA (System for Automated Geoscientific Analyses) GIS 2.1.2, the NDVI values were then overlaid and mapped into the green areas of Universitas Indonesia Campus, Depok,West Java. The vegetation covers are then categorized and classified by using NDVI as follows (Suwanto *et al*. 2021):

- if 0< NDVI <0.3 then vegetation covers are <50%;
- if 0.31< NDVI <0.4 then vegetation covers are 50–69%;
- if 0.41< NDVI <1.0 then f vegetation covers are 70–100%. This NDVI is a proxy of habitat quality informing habitat suitability for the snakes.

Statistical Analysis

Statistical analysis was used to observe the correlations of Kernel Density with the ecological covariate that in this study was the NDVI. The statistical analysis used was the calculations of Area under the Curve (AuC) of Receiver Operating Characteristic (ROC).

RESULTS AND DISCUSSION

Studies of snake movement frequently report home range sizes considering that these data are important key to our understanding of snake ecology and this also applied to *N. sputatrix*. This study has revealed the uses of 2 principal methods that are Convex Polygon (CP) and Kernel Density (KD) to elaborate and provide better understanding of the *N. sputatrix* home range within the campus environment. This study is very important to contribute to the both snake conservation and sustainable development. The identification of home range can be used to delineate an area that should be protected and other areas that can be utilized for development.

During the study's one-month period, a total of 108 adult individuals identified as *N. sputatrix* were captured and recorded for their geocoordinate locations. The average and 95% confidence interval of the SVL of captured snakes were 1.37 m (95% CI: 0.941 m to 1.8 m).

The home range models are available in Figure 2 with 3 models are available including Convex Polygon model (CP) (Figure 2.a), Kernel Density (KD) with reference h bandwith value (KD_{href}) (Figure 2.b), and KD with least-squares cross-validation or KD_{hLSCV} (Figure 2.c).

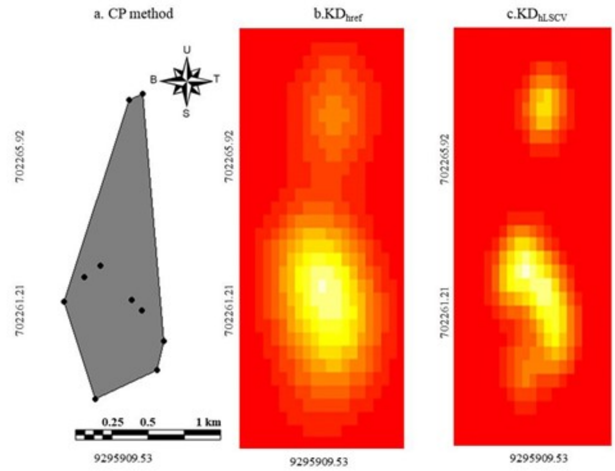

Figure 2. Home range models for *N. sputatrix* at the green areas of Universitas Indonesia Campus (a.CP method, b.KD_{href}, c. KD_{hLSCV}).

In the KD_{href} and KD_{hLSCV} home range models, the density estimate is shown as yellow shading. The first model (Figure 2.a) is the CP home range model that includes all spaces as the potential home range of *N. sputatrix.* This model indicated the home range of the cobra was extended from the South to North parts of campus. Similar to CP*,* both *KD* home range model whether they were KD_{href} or KD_{hLSCV} showing coverages of *N. sputatrix* home range extended from the South to North. Albeit, the KD_{hLSCV} model (Figure 2.c) shown the home range was separated into 2 patches that are Northern and Southern part patches.

Based on the calculation, the Convex Polygon analysis shows that approximately 114.53 Ha or equals to 35.79% of green areas of Universitas Indonesia Campus was the home ranges of the cobra. While, based on the Kernel Density analysis, it confirms that up to 307.65 Ha or equals to 96.14% of green areas of Universitas Indonesia Campus were potentials as the home ranges of the cobra.

Figure 3 shows at what home range sizes the *N. sputatrix* spent most of the time. According to the graph, there is a probability less than 90% that *N. sputatrix* requires home range sizing 0-55 Ha. In contrast, there is a probability more than 90% that *N. sputatrix* requires home range sizing more than 55 Ha.

Large home ranges of the cobra within green areas of Universitas Indonesia Campus are related and regulated by various factors including biological and environmental factors. In

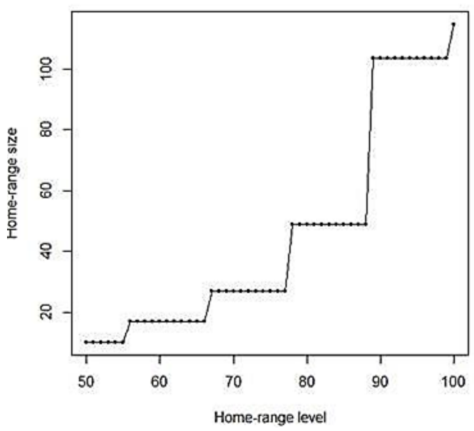

Figure 3. Home range level of *N. sputatrix* at the green areas of Universitas Indonesia Campus.

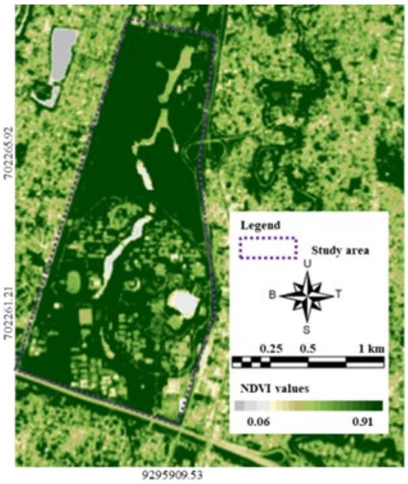

Figure 4. NDVI of the green areas of Universitas Indonesia Campus.

this study, the measured environmental factor was the NDVI (Figure 4). Based on the statistical analysis, the fitted Area under the Curve (AuC) of Receiver Operating Characteristic (ROC) was 0.709 (Figure 5, Table 2) and this shows positive correlations and effect of NDVI on Kernel Density. Vast green areas with high NDVI values (>0.5) were supporting the size of home range. High NDVI means the presences of vegetated areas and less anthropogenic influences that provide suitable habitats for either the snakes or their prey. This finding is in agreement with result from Di Cola *et al*. (2008) that among different environmental variables ranged from precipitation, NDVI, land surface temperature and altitude, the snakes would be more frequent in areas with high levels of NDVI,

Regarding biological factors, body sizes of snakes can regulate the home range sizes with converse relationships. According to Putman *et al*. (2013), a variety of factors influence the home ranges of animals can be ranging from sex, body size, season, and abiotic factors that are vary greatly within and across populations and species. As a comparison to venomous and predatory cobra studied here, the Northern Pacific Rattlesnake (*Crotalus oreganus oreganus*) males that had larger sizes than female were also had bigger home range sizes than females. In corroboration with this, a Burmese python, the largest terrestrial was known to have home ranges sizing 2,250 Ha as observed in Everglades National Park of Florida (Hart *et al*. 2015). *Ophiophagus hannah*, a venomous snake that also has large size and has close taxonomy relationship with cobra was known has a maximum home range reaching 1,794.3 Ha (Silva *et al*. 2018, Silva *et al.* 2020). Among snakes that are common in general urban green areas and in particular Universitas Indonesia Campus environments, *N. sputatrix* was considerably has larger body size that this cobra can grow up to 1.8 m as measured in adult male. This considerable size explains the home range sizes of the *N. sputatrix.*

Large body size owned by *N. sputatrix* promotes this species to expand its home range to find more food resources. Albeit the food resources are scarce, this scarcity does not influence and limit the home ranges of *N. sputatrix* (Silva *et al*. 2018). Comparable with this condition, some snakes were known can travel far distance with the absence of food

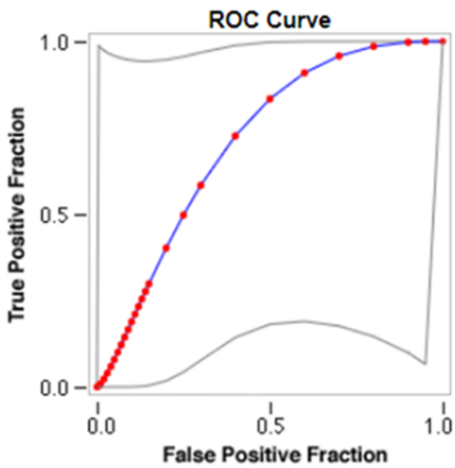

Figure 5. ROC curve with fitted ROC area (0.709) showing correlation of Kernel Density values with NDVI.

Table 1. Home range comparisons across snake species, ecosystem, continent, and methods.

Species	Size (Ha)	Ecosystem-continent	Methods
Eastern Hog-nosed Snake *Heterodon platirhinos*[a]	23.7	Forest-America	CP, KD
Smooth snake-*Coronella austriaca*[b]	3.8	Forest-Europe	CP
Eastern Rat Snake *Pantherophis alleghaniensis*[c]	13.6	Forest-America	CP
Broad headed snake *Hoplocephalus bungaroides*[d]	9.8	Forest-Australia	CP
Giant pythons *Simalia amethistina*[e]	60	Forest-Australia	CP, KD, Brownian Bridge Movements
Equatorial Spitting Cobra-*Naja sputatrix* (this study)	114.53	Urban forest-Southeast Asian	CP, KD

resources. Study on venomous Western Diamond -Backed Rattlesnake (*Crotalus atrox*) found that unfed control groups were showing no difference in home range size in comparison to group provided with the prey.

The KD_{hLSCV} model shown the home range was separated into 2 patches that are Northern and Southern part patches. This indicates the absences of *N. sputatrix* due to the presences of barriers within its home ranges in campus ecosystems. A barrier that limits and reduces snake home range mostly are due to the presences of massive anthropogenic structures including settlements, paved, graded dirt road, and asphalt roads (Miller *et al*. 2012). Based on personal observations, green areas of the Universitas Indonesia Campus were bordered with asphalt road networks, fragmenting the green areas. In spite of the road's presence, the width of the road also added a potential obstacle and barrier for the snakes. In fact, the width of the road ranged from 3 to 6 meters in some areas. In Everglades National Park, roads can serve as either a potential barrier for snake that responsible for approximately 37% of road-caused mortality in snakes. The home range patchiness observed in this study using KD_{hLSCV} was also in agreement with the previous study. Silva *et al*. (2018) stated that the KD_{hLSCV} model was characterized by production of largest, patchiest estimates, combined with the longest boundaries relative to area. Albeit, KD_{href} was characterized by production of the lowest complexity.

Table 1 shows comparisons of home ranges across species, ecosystems, continents, and methods. The methods used in this study are in comparison with other studies and have contributed to the home range studies on particular snake species, mainly in Southeast Asian countries. This study is important since most of the studies were implemented in the temperate region and the nearby locations were in tropical Australia. The home range of the snake species in this study seems larger in comparison to other reported species. This

Table 2. Area under the Curve (AuC) of Receiver Operating Characteristic (ROC) variables.

Fitted ROC area	Accuracy	Sensitivity	Specificity
0.709	66.7%	83.3%	50%

happens since the cobra is a predatory species and has the ability to forage at a farther distance to search for its prey in comparisons to other predatory snake species that has less ability to forage. Besides that, the study was conducted in an urban forest influenced by anthropogenic influences indicated by the presences of buildings and streets and lower NDVI values than NDVI in vegetated areas that also cause species to forage more at a distance and expand their home range sizes. Home-range size of a species increased in areas with low availability of forest cover, as common in urban forest settings in this study. In fact, the foraging distance is also related to body size. Rao *et al*. (2013) confirmed that the cobra, as a large predatory species, has an ability to forage over long distances due to its body size (Bhaisare *et al*. 2010).

CONCLUSION

Based on the result, it can be concluded that approximately 114.53 Ha or equals to 35.79% of green areas of Universitas Indonesia Campus was the home ranges of the cobra according to Convex Polygon. While, based on the Kernel Density analysis, it confirms that up to 307.65 Ha or equals to 96.14% of green areas of Universitas Indonesia Campus was home ranges. Moreover, there is a probability less than 90% that *N. sputatrix* requires home range sizing 0-55 Ha. In contrast, there is a probability more than 90% that *N. sputatrix* requires home range sizing more than 55 Ha.

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